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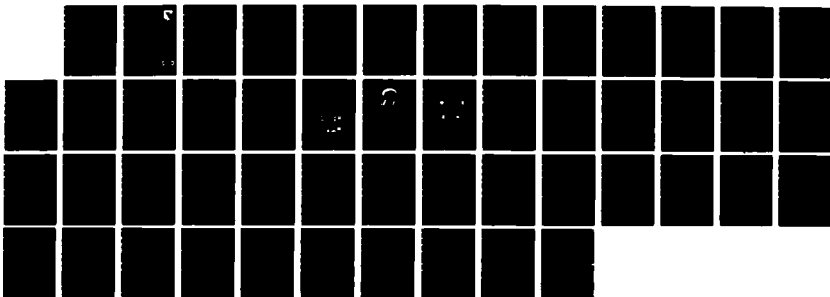
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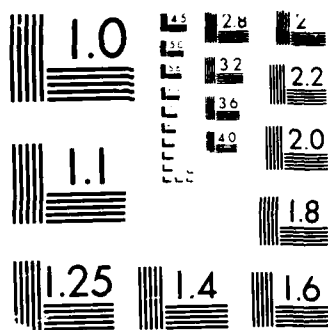
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EYE AND HEAD RESPONSE TO AN ATTENTION CUE
IN A DUAL TASK PARADIGM (U)



GLORIA L. CALHOUN

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

JULY 1987

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ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
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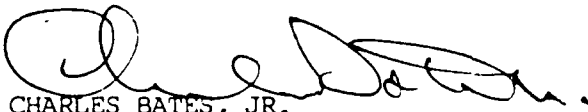
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FOR THE COMMANDER



CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Eight subjects were used to characterize eye and head movements in response to a cue to re-fixate in a dual task paradigm. The subject's tasks were to complete a centrally located pursuit tracking task and identify targets which were vertically displaced from the normal line-of-sight. Reaction time and movement pattern of the eye and head were recorded as well as conventional performance measures for the following: 1) two difficulty levels of the tracking task; 2) presence and absence of an attention cue prior to target presentation; and 3) two target locations which were vertically displaced from the centrally located task. The results indicated that eye and manual reaction time increase the farther a target is vertically displaced from the centrally located task and head reaction time decreases with the presence of a verbal cue prior to target presentation. Since the experimental conditions examined in the present study affected these measures differently, eye, head, and manual reaction times should be examined further. The differences found in eye and head response (Continued)					
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as a function of information location and presence of an attention cue suggest that such unobtrusive measures may be valuable in the design of multifunction display symbology and attention cueing systems. (Keywords: oculometer parameters; eye reaction time man machine systems),

PREFACE

This technical report is the result of research performed at the Visual Display Systems Branch (HEA), Human Engineering Division, Armstrong Aerospace Medical Research Laboratory (AAMRL), Wright-Patterson Air Force Base, Ohio. Ms. Jenny Huang of Systems Research Laboratory, Inc. (SRL) provided software support and Dr. Christopher Arbak (SRL) and Mr. William Janson (Synergy, Inc.) provided human factors support, particularly in the data collection and analysis phases. The effort was accomplished under Work Unit 71842602 between April 1984 and December 1984. The SRL/Synergy portion of this effort was performed in support of the USAF AAMRL under contract number F33615-82-C-0511.



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TABLE OF CONTENTS

	Page
INTRODUCTION	5
LITERATURE REVIEW	5
Eye and Head Patterns	6
Classical movement pattern	7
Simultaneous movement pattern	7
Predictive movement pattern	7
Factors Affecting Eye and Head Response to Cues	9
Theories of Attention	11
Bottleneck theories	12
Capacity theories	12
Attention and eye/head movement	13
Purpose	13
METHOD	14
Apparatus	14
Experimental facility	14
Eye movement recording system	14
Head movement recording system	16
Supporting computer/software system	16
Simulator	17
Subjects	18
Experimental Design	18
Subject's Tasks	19
Centrally located task	19
Peripherally located task	20
Trial Structure	20
Performance Measures	20
Procedures	22
Linearization	22
Set up	22
Experimental session	22
RESULTS	23
Data Treatment for Analyses	23
Tracking performance	23
Accuracy of peripheral task	24
Performance as a function of target letter	24
Initial eye and head position check	24
Data Analysis	27
Eye reaction time	27
Head reaction time	29
Manual reaction time	29
Eye and head movement pattern	30
Summary of Results	33
DISCUSSION	33
Eye and Head Response	34
Factors Affecting Eye, Head, and Manual Reaction Time	35
Dual Task Paradigm	35
Cue condition	36
CONCLUSIONS	37
APPENDIX	38
REFERENCES	42

LIST OF FIGURES

Figure	Page
1. Classical and predictive eye and head movement patterns . .	8
2. Overall configuration of the facility	14
3. Schematic illustration of subject's helmet	15
4. Illustration of the differential movement of the corneal reflection with respect to the pupil	16
5. Schematic illustration of cockpit simulator	17
6. Experimental design	18
7. Time lines showing structure of the trials in each run . .	21
8. Mean manual, head, and eye reaction time with each level of tracking difficulty.	27
9. Mean manual, head, and eye reaction time with cue absent and cue present conditions.	28
10. Mean manual, head, and eye reaction time with upper and lower target locations.	28
11. Mean eye reaction time for each level of tracking difficulty as a function of target location.	29

LIST OF TABLES

Table	Page
1. Variables Addressed in the Study	23
2. Summary of Analysis of Variance of Tracking RMS Error . . .	23
3. Frequency of Errors for each Experimental Condition	24
4. Frequency of Trials in Which the Initial Eye or Head Position was Down	25
5. Summary of Analysis of Variance of Frequency of Trial Deletions due to Initial Eye Position	26
6. Summary of Analysis of Variance of Frequency of Trial Deletions due to Initial Head Position	26
7. Summary of Analysis of Variance of Mean Eye Reaction Time .	30
8. Summary of Analysis of Variance of Mean Manual Reaction Time	30
9a. Frequency of Trials Showing Classical Eye and Head Movement Pattern 31	31
9b. Frequency of Trials Showing Predictive Eye and Head Movement Pattern 32	32
10. Summary of Analysis of Variance of Frequency of Trials Showing Classical Pattern	32
11. Summary of the Effects of Each Variable on Reaction Time Measures	33

I. INTRODUCTION

As a result of significant increases in the application of digital computers to system design (e.g., in cockpits and nuclear power plant control rooms), more information can be made available to the system operator. In order to assist the operator in monitoring this information, warning or alerting devices have been added as needs are identified. This has resulted in an overabundance of attention-getting lights and sounds which may tax the operator's ability to perceive, interpret, and react to the information. Unfortunately, past approaches to designing attention cueing systems have not capitalized on the human's sensory and perceptual capabilities or recognized performance limitations in a concurrent task environment. Rather, most are based solely on performance data, such as manual reaction time, collected when the operator is attending to only one task (Senders, 1976). Consequently, there are inadequate data pertaining to attention cueing systems for an operator performing multiple tasks.

Since most information displayed in current human-machine systems is through the visual channel, measures of eye movement data may be indicative of the effectiveness of candidate cues in directing attention to a particular display or control (Stern, 1980). For the most part, eye direction has not been a dependent variable in past attention studies. Moreover, little effort has been concerned with relating eye and head movements in complex tasks to the manner in which the operator's attention is directed and information is processed (Robinson and Rath, 1976). The purpose of this study, therefore, was to examine eye and head response (reaction time and overall movement pattern) to a cue to refixate. A dual task paradigm was employed in which a concurrent task was interrupted by auditory refixation cues. The refixation task involved targets which were vertically displaced from the normal line-of-sight by approximately 28 degrees, thus requiring eye movement and probably some head movement. The subject's concurrent task was to complete a manual tracking task on a centrally located monitor. Several difficulty levels of the centrally located tracking task and two locations of the target on the peripherally located monitor were examined to determine the effect of such factors on eye and head movements. This study investigated whether measures characterizing eye and head movements are useful for the evaluation of attention cueing techniques.

As is common when performance of a human operated system is evaluated, diverse areas of knowledge must be integrated to design and conduct a useful study. In particular, the area of eye and head dynamics and the area of attention and arousal bear on the human's response to attention cues. The following section reviews the available literature in these areas.

II. LITERATURE REVIEW

Prior to the last decade, most eye movement research required fixing the head in order to obtain precise measurements. However, recent

technological developments enabling accurate simultaneous eye and head movement recording have renewed interest in studying eye dynamics when the head is free. Examination of eye movement with the head free is very desirable since eye-head coupling is a "natural behavior" in an orientation experimental paradigm. If an individual is instructed to look at a target both head and eyes turn towards it, even if the target is well inside the range of normal eye movements (Morasso, Sandini, Tagliasco, and Zaccaria, 1977). In fact, the nature of the saccadic eye movements and the dynamic pattern of eye and head shifts are both qualitatively different when the head is free (Robinson, 1979). It is this characteristic of eye and head movements during visual refixation which may serve as objective indicators of the effectiveness of candidate cues in attention system design. Several distinct patterns of eye and head movements are described next, followed by a consideration of eye and head response to cues.

EYE AND HEAD PATTERNS:

Eye and head movements occur together during wide angle refixations. The control system for the eye movements is generally saccadic, thus allowing rapid, preprogrammed movements to acquire a new display. For refixating up to 20 degrees, one saccade will normally be executed and take approximately 67 ms. Either 1 or 2 saccades may occur for angles greater than 20 degrees. (Maximum velocity for saccades over 20 degrees is about 550 degrees per second. A saccade of 40 degrees takes roughly 135 ms; Robinson, 1979). If there are 2 saccades, they both appear to be programmed in advance with less than 25 ms between them and consist of a large amplitude saccade covering approximately 90 percent of the distance followed by a smaller corrective saccade (Becker and Fuchs, 1969).

Head movements have been observed to occur at target angles as small as 10-20 degrees horizontally from the point of initial fixation (Vossius, 1972), but more frequently occur at angles greater than 30-40 degrees (Bartz, 1966). (In a study by Robinson and Bond (1975), the head movements that occurred for a 30 degree target angle had an angular deflection of less than 5 degrees.) Sanders (1970) has identified three functional visual fields, based on target angles, which determine whether eye or head movements occur in acquiring targets in the horizontal periphery. They are the: (1) stationary field where peripheral viewing is sufficient; (2) eye field where eye movements are required to refixate a target; and (3) head field where head movements are also necessary. The actual size of each horizontal visual field has been found to vary as a function of the complexity of the target and nature of the task. These factors probably also influence visual perception in the vertical plane. For instance, wearing an oxygen mask reduces a fighter pilot's vision for large angles below the horizontal and consequently would probably increase the use of head movement in refixations.

Unfortunately, the research to date has focused on examining targets on the horizontal plane. Little research has addressed whether there are functional visual fields in acquiring targets in the vertical periphery similar to those found for the horizontal periphery. Robinson (1979), however, postulates that eye and head movement dynamics are similar in any

direction. He bases this on Yarbus's (1967) finding that saccade velocity does not differ at angles off the horizontal and that head velocities for horizontal refixations are well below the maximum attainable head velocity. In contrast, Cox (1971) reports that subjects completing a manual tracking task found it much more difficult to read dials above eye level than in a horizontal plane or downwards in the vertical plane.

Examination of the horizontal plane has also dominated most, if not all, the research addressing whether the eye or head moves first during refixations on targets in the "head field". Additional data are needed to show if the sequence in which the eye and head move is similar for targets in the vertical plane. First, though, the three distinct patterns (i.e., sequence) of eye and head movement reported in the literature will be described.

Classical Movement Pattern. In the typical or "classical" response, the eyes move first towards a target appearing in the visual field, followed by a head movement, up to 50 ms later, in the same direction (Bartz, 1966; Bizzi, 1974; Robinson, Koth, and Ringenback, 1976). The eyes, moving with greater velocity, reach the target first and then begin a counter movement with respect to the head to compensate for the continuing head rotation. During this period of "dynamic fixation" or eye/head compensation, the eye moves back towards the center of its orbit with a velocity matching the corresponding head velocity, thus keeping the fixation stationary for visual processing and returning the eye towards its central position, thereby allowing maximum flexibility for the next saccade. Although the eye is capable of compensating for head velocities up to 300 degrees per second, during dynamic fixation periods, head (and thus eye) velocities are typically in the range of 50-100 degrees per second. These dynamic fixation periods usually last for 150-200 ms. Once both eye and head movement cease, "static fixation" of the target begins (Robinson, 1979).

Dynamic fixation was observed by Sanders (1970) only after target acquisition. Bartz (1966), however, has demonstrated that with complex visual stimuli as targets, the compensatory movement occurs before the eye reaches the target, suggesting that the movement is initiated by peripheral rather than foveal stimulation. Vossius (1972) found that some compensation occurs before acquisition if the initial saccade does not acquire the target and compensation after if the target was acquired by the initial saccade. These compensatory adjustments may constitute some type of error minimizing feedback from the control system (Bizzi, 1974).

Simultaneous Movement Pattern. Sanders (1970) reported a second pattern of eye/head coordination that is distinct from the classical pattern in that the eye and head begin to move almost simultaneously. Once the eye reaches the target, the head begins to decelerate and the eye makes a compensatory movement to remain fixated on the target.

Predictive Movement Pattern. A third pattern has emerged in the last decade in studies where the coordination of eye and head movements was not elicited by the appearance of a visual target, i.e., not visually triggered (Bizzi, 1974). In these studies, an initial compensatory pattern, termed

hereafter as "predictive", was observed in which the head moves first while the eyes remain fixated in the starting position. In this manner, the eye is moving negatively with respect to the head for a brief period before a saccade is initiated (Nelson, London, and Robinson, 1978). This predictive pattern is in contrast to the classical pattern in which the eye moves toward the target about 50 ms before the head (Figure 1).

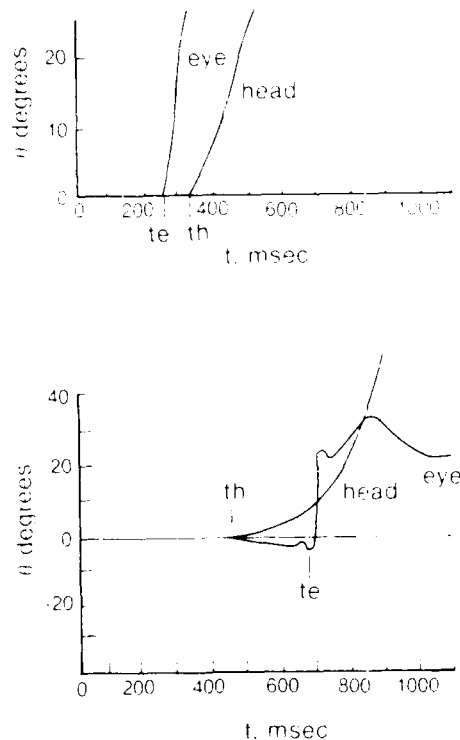


Figure 1. Classical (top) and predictive (bottom) eye and head movement patterns (t_e =eye reaction time and t_h =head reaction time) (Figure from Robinson and Bond, 1975, p.6)

One task paradigm in which this predictive pattern was observed involved monkeys memorizing a set of reward contingencies and then making an appropriate predictive movement in anticipation of the presentation of a visual stimulus. Bizzi (1974) determined that it was the monkey's vestibular system which controlled the initial compensatory eye movement. The predictive pattern also occurs in paradigms where a human's processing of centrally located information is interrupted to perform a task requiring fixation of a peripherally located target. For instance this pattern has been observed in actual automobile driving situations where drivers have to monitor the forward scene in order to control the path of the vehicle and also direct their eyes to look into the vehicle's mirrors. This allows the drivers to maintain foveal fixation on the central control task (Mourant and Grimson, 1977). In fact, Nelson, et al. (1978) report that the percent of

predictive patterns and the number of subjects using such a pattern increases as the complexity of the centrally located information to be processed (symbolic versus geometric direction command) increases.

In the predictive pattern, the head begins its movement towards the periphery while the eye remains centrally fixated, thus delaying the onset of the first saccade by 100-200 ms and enabling the operator to spend more time on the centrally located task before attending to the peripheral task. According to data collected by Robinson (1979), the angle through which the initial compensatory movement occurs is usually less than 15 degrees, but has been observed frequently for only 5 or 10 degrees. The data further indicate that, unrelated to handedness, some subjects compensate on either the right or left side, some to one side only, and some never at all (Nelson, et al., 1978).

Results such as these, which indicate that the coordination of eye and head movements is situation specific rather than fixed, suggest that eye and head movements have important implications to attention system design. In determining whether eye and head movement measures can serve as effective evaluators of attention cues, it is necessary to examine the factors affecting the reaction time and overall movement pattern of the eye and head to a cue. The following section will review the literature pertaining to factors affecting eye and head movements in response to cues.

FACTORS AFFECTING EYE AND HEAD RESPONSE TO CUES:

There are very few data pertaining to head movement latency to a refixation cue. In contrast, eye reaction time was quantified as early as 1908 and was found to range from 180 to 230 ms (Robinson, et al., 1976). Since these studies typically involve only a small number of highly practiced subjects changing their fixation between two points, with the head fixed, it is likely that the results are not applicable to more complex situations. In fact, one study (Carlow, Dell'Osso, Troost, Daroff, Birkett, 1975) found that eye reaction time (mean = 255 ms) increased as uncertainty increased in a disjunctive task where subjects made a response to either a step or pulse-step target motion to either the right or left. In another experiment involving auditory stimuli, eye reaction time averaged 250 ms in a simple task, whereas reaction time averaged 390 ms in a choice task (Bertera, Callan, Parsons, and Pishkin, 1975).

A number of stimulus variables have also been shown to affect reaction time. For instance, knowledge of a target's location prior to beginning the search has been found to decrease reaction time for both the eye and head movement (Miller, 1969; Becker and Fuchs, 1969; Bizzi, 1974; Robinson et al., 1976). A geometric as opposed to a symbolic directional command can also decrease eye reaction time (Nelson, et al., 1978). The effect of target discriminability was found by Robinson, et al. (1976) to be the same for eye and head, i.e., reaction times were faster with dim targets compared to results with bright ones. Robinson, et al. commented, however, that this last finding "has no apparent explanation and is at variance with decreases in total search times usually found with increased target visibility" (1976, p. 705).

Another variable found to consistently decrease eye reaction time is the presence of a nonspecific warning event preceding the onset of a peripheral target (Saslow, 1967; Becker, 1972; Cohen and Ross, 1973). In general, the reaction time becomes faster as the warning interval between the signal and target onset increases to about 600 ms (Saslow, 1967; Cohen and Ross, 1978). It was initially thought that this warning effect was due to a reduction in the frequency of the small corrective saccades that occur following the offset of a fixation stimulus. The refractory effects accompanying fixation microsaccades were also discussed by Carpenter (1977) as a factor that might affect saccadic latency following a warning event. The results of Ross and Ross (1980), however, showing that either stimulus onset, change, or offset is a sufficient warning event for a reduction in eye reaction time, suggest that microsaccades are not necessary for a warning signal to affect eye reaction time. Rather, Ross and Ross (1980) concluded that faster eye response following a warning is due to a general preparatory or alerting process that affects the processing of the target (e.g., shorten initiation time and/or duration of signal processing) or the programming of the saccade to the target. Ross and Ross (1980) also found that a visual signal onset was not only less effective as a warning compared to the other conditions examined, but it resulted in an interference or delay in the saccadic response to the peripheral target. A later study indicated that the onset-offset effects are limited to visual signals (Ross and Ross, 1981).

Perhaps one of the most critical factors affecting eye and head reaction time to peripheral targets, however, is the presence, and assumed importance, of an ongoing or interrupted task (Robinson, 1979). Eye reaction times in paradigms in which the command to refixate is given while the subject is engaged in a tracking task can be more than double (i.e., 350-550 ms) those found in traditional refixation experiments involving only one task (Robinson and Subelman, 1975). Moreover, increases to 700 ms can result from using a paradigm wherein an ongoing control task must be interrupted in combination with other factors found to affect response time (Robinson, 1979). These increases in eye reaction time can be attributed, in part, to the subject's frequent use of a predictive pattern in a dual task paradigm. With the predictive pattern, not only are the movements reversed with the head response preceding the eye response, but the initial movement is later, the delay between the eye and head response is increased by a factor of four and the correlation between eye and head reaction time is reduced (correlation of eye and head reaction times with predictive and classical patterns = .76 and .98, respectively; Robinson and Bond, 1975).

The predictive eye and head movement pattern may also account for the increase in eye reaction time as the angle of the target increases from a centrally located point. Robinson and Bond (1975) found a linear 2 ms per degree rate of increase in eye reaction time for display angles between 30 and 120 degrees. Their subjects frequently used a predictive pattern in interrupting an ongoing manual task to complete a refixation task. In contrast, Robinson, et al. (1976) using a paradigm without an ongoing task, found that eye reaction time is not a function of display angle. Unfortunately, results from other studies do not support this reasoning. For instance, Bartz (1962) found that eye reaction time was relatively

constant at display angles of 10 degrees or less, but increased linearly at a rate of 1.5 ms per degree beyond 10 degrees. Also Fuchs (1971) reported that with the head fixed, eye reaction time in response to nonpredictable targets increased with saccadic magnitude. Thus the effect of horizontal target angle on eye reaction time has not been determined conclusively. In addition, the effect of targets at various vertical angles has not been addressed.

The results of past research are also inconclusive regarding the effect of tracking variables on eye and head dynamics when the subject is required to refixate on a peripheral target. Robinson and Bond (1975) examined the pattern of eye and head movements under two control system orders (zero and second order) and two command signal bandwidths (low: 0-.16 Hz and high: 0-1.00 Hz). The only significant effect was that, in the low bandwidth condition, eye reaction times for trials in which the pursuit tracking performance was "out-of-control" (defined by a mean-squared-error performance index) exceeded by 35 ms that for the trials in which performance was "in-control". They argue that the subject may be hesitant to refixate when in an "out-of-control" condition, due to the high control error incurred by such a move. It is not clear, however, how the authors account for the mean reaction times across all trials being longer in the easier low bandwidth condition than in the high bandwidth condition. It could be that the higher bandwidth task was so difficult that the subjects were out-of-control for the majority of each trial and had nothing to lose by diverting their attention to the peripheral task. With the low bandwidth condition, it may have been more logical for the subjects to delay their eye response, especially when out-of-control, in order to make a few more inputs to the tracking task. In fact, Robinson and Bond (1975) did find a higher incidence of predictive eye and head movement patterns with the lower order control system and lower bandwidth condition. The authors' conclusion supports this hypothesis--they state that the small control status effects were related to the high bandwidth and fast dynamic systems employed. They further suggest that subsequent research address lower bandwidths and more sluggish systems.

A lower bandwidth (.10 Hz; second order tracking task) was examined in a later study by Robinson and Rath (1976) and predictive eye and head movements were observed. However, the mean eye reaction time for the even lower bandwidth was shorter than that predicted by the trend found by Robinson and Bond (1976). Furthermore, an increase in eye reaction time was not found for an out-of-control condition. These differences may be due to the dynamically slower system used by Robinson and Rath (1976; 1.0 cm/sec²) compared to that used by Robinson and Bond for their second order condition (1975; 2.5 cm/sec²).

THEORIES OF ATTENTION:

The preceding review has shown that eye and head movement dynamics and reaction time can be qualitatively different in a dual task paradigm compared to data in a single task paradigm. Furthermore, the last study cited (Robinson and Bond, 1975) suggested that eye and head movements may be affected by the difficulty (i.e., tracking bandwidth) of the tasks to be

performed. Results, similar to these, from studies examining conventional manual reaction time have undergone considerable interpretation with respect to theories of attention and arousal. A few of these theories will be briefly described below.

Bottleneck Theories. One class of attention theories has been referred to as "bottleneck" since they propose that a particular stage of the information flow between sensory input and response is the limiting factor. One distinguishing factor between the various bottleneck theories is where they assume the single-channel to exist. Broadbent (1971) proposed in his filter theory that inputs are processed in parallel in the sensory register. After that a hierarchical filtering process occurs whereby inputs are handled serially and the order in which the inputs are processed is determined by what features they have in common. This process reduces the number of inputs to the nervous system and thus can be viewed as a mechanism for focusing attention on certain categories of inputs. In contrast, the theory proposed by Deutsch and Deutsch (1963) places the limitation at the response selection stage and assumes that both sensory inputs and processing are not serial. Both of these theories imply that a complex task will take more time than a simple one and the severity of interference between two tasks increases with the duration of the delay (Kahneman, 1973).

Capacity Theories. Subsequent research examining reaction time distributions under focused and divided attention conditions and the effect of channel bias on the detection of a highly significant target suggested that there is no single channel bottleneck in the perceptual system (Kahneman, 1973). Rather, the research suggested that parallel processing of simultaneous inputs occurs and is only limited by the total information processing resources available to the human. These "capacity" theories are based on the assumption that there is a pool of information processing resources which are allocated over the subprocesses (Kahneman, 1973). The multiple resource model (Norman and Bobrow, 1976; Navon and Gopher, 1979) is similar except that it proposes multiple specialized resources, rather than a unitary pool of non-specialized resources. According to this construct, performance on concurrent tasks is a function of the demands that these tasks impose on the limited capacity system. In turn, the resources can be allocated in a flexible manner over the various processes making up the multiple tasks. As more resources are invested, performance will improve up to the point at which no further increase in performance is possible. At this point, the task is said to be data-limited. In a resource-limited task, performance changes with added or depleted resources (Wickens, 1981). Kahneman (1973) describes how arousal level can influence resource allocation. An approximately even distribution of attention among concurrent activities may only be possible at a low level of arousal. When arousal is high, the allocation of resources becomes both more uneven and less precise. Performance is especially impaired under high arousal when the human is to divide attention over a broad range of information processing activities or make fine discriminations. Easterbrook (1959) explained these results in terms of the Yerkes-Dodson law. When arousal is low, selectivity is also low and the human tends to accept irrelevant cues. As arousal increases, selectivity also increases, resulting in improved performance since irrelevant cues are more frequently rejected. However, at

even higher levels of arousal, the continuing increase in selectivity results in relevant cues being rejected and performance deteriorating. Using this logic, performance on simple tasks, which typically use fewer cues, is improved when the human's arousal level is relatively high. When the human is over-aroused, according to Easterbrook, performance tends to be poorer in complex tasks and better in simple tasks.

One experiment, which supports the narrowing of attention under high arousal, examined subject's performance in a dual task paradigm: continuous tracking and monitoring of occasional targets in the visual periphery (Bahrick, Fitts, and Rankin, 1952). The results indicated that performance on the peripheral task deteriorated when the incentive for good performance on the centrally located tracking task was increased. A similar "perceptual narrowing" has been reported elsewhere (Mackworth, 1965; Bursill, 1958; Leibowitz, 1973). According to a study by Hockey (1970), this cue selectivity is not a function of physical location, but rather of the strategy employed, whether based on differential instruction (primary versus secondary task) or on induced expectancy (high versus low signal probability). This finding implies that "funnelling" is not an actual contraction of the visual field but rather a change in how attention and effort are allocated under high arousal.

Attention and Eye/Head Movement. It is unknown whether this effect of arousal on attention allocation strategy, postulated to explain manual response data, also applies to eye and head movement dynamics. While saccadic and manual responses have been shown to have some similar properties (e.g., reduced latency after warnings), the response systems also differ in many ways. First, the saccadic response is generally considered more automatic compared to the manual response. This is in contrast to typical reaction time studies where subjects have limited practice in pairing a stimulus with some type of response (e.g., key press). Second, due to the programmed characteristics of saccades, the speed-accuracy tradeoff and response criterion factors associated with manual responses may not pertain to saccadic responses. For instance, Cohen and Ross (1978) found saccadic response latency to be independent of accuracy under warning signal conditions. Such differences suggest that not only eye reaction times but eye and head movement parameters in general be studied with respect to attention and arousal interpretations.

PURPOSE:

The present experiment was designed to elucidate several of the unexplored issues in eye and head movements in response to a cue. As mentioned above, little work has been accomplished in qualitatively and quantitatively describing the eye and head response after a cue to refixate in a dual task paradigm. In particular there is a dearth of research pertaining to refixations when the targets are vertically displaced from the normal line-of-sight. Moreover, variation of the difficulty of the centrally located tracking task has seldom been made. In view of the lack of data in these areas, the present experiment employed a dual task paradigm to characterize the eye and head response (reaction time and overall movement pattern) for the following: a) two difficulty levels of the

centrally located tracking task; b) presence and absence of an attention cue prior to target presentation; and c) two target locations which were vertically displaced from the centrally located task. Conventional performance measures (manual reaction time and accuracy) were also recorded during refixations in order to compare eye/head movement measures to conventional measures, as dependent variables in the evaluation of the effectiveness of an attention cue. Additionally, this made it possible to examine whether the effect of arousal on attention allocation strategy postulated to explain manual response data also applies to eye and head movements.

III. METHOD

APPARATUS:

Experimental Facility. The research was conducted on the Helmet-Mounted Oculometer Facility (HMOF) residing at the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base. The overall configuration of the facility is shown in Figure 2. The key components of the facility which pertain to this study are described below.

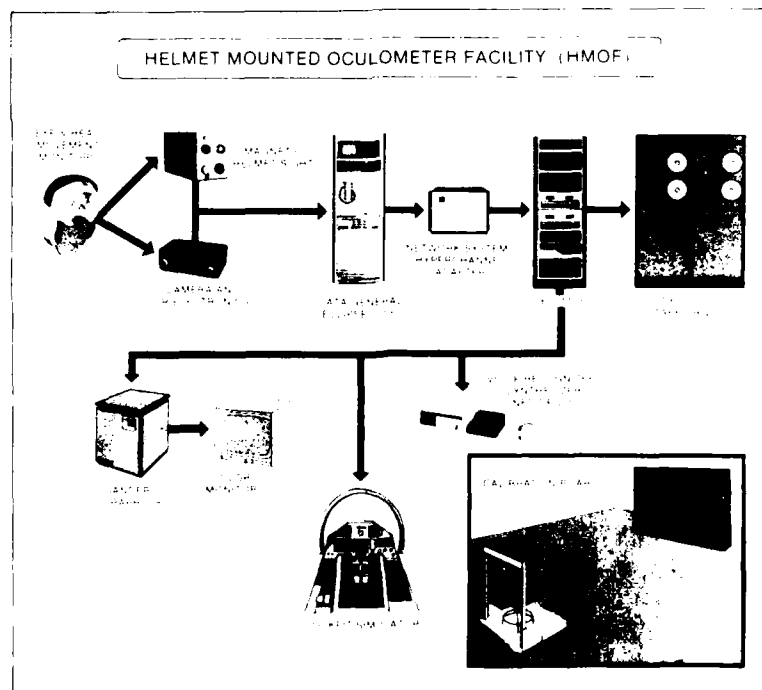


Figure 2. Overall configuration of the facility.

Eye Movement Recording System. The movement of the eye with respect to the head was measured with an infrared corneal reflection system (modified Honeywell Helmet Mounted Oculometer; see Figure 3).



Figure 3. Schematic illustration of subject's helmet.

The subject's eye was illuminated by a halogen lamp filtered to pass near-infrared light. This light was collimated and reflected from a small coating on a parabolic helmet visor into the subject's right eye. Some light was reflected from the cornea and a portion of the light that entered the pupil was reflected by the retina, passed out of the eye through the pupil, and was scanned by a miniature charge coupled device (CCD) video camera. The video signals from the camera contained bright spots, a bright disk, and spurious background reflections. The bright spots resulted from tearing and reflections of the light source from the surface of the cornea and the bright disk was the reflected energy from the retina after it had passed through the pupil.

Because the cornea and the rest of the eye have different radii of curvature, as the eye rotates about its center of rotation to look around the visual field, the corneal reflection moves differentially with respect to the pupil (Figure 4). Thus, eye direction could be determined by complex signal processing which sorted pupil and corneal reflections, determined the relative positions of the center of the pupil and the center of the corneal reflection, rejected tearing, and took into account the linearization of raw data to determine true azimuth and elevation angles with respect to the helmet.

Head Movement Recording System. A Honeywell magnetic Helmet Mounted Sight (HMS) provided accurate helmet position and attitude determination in six degrees-of-freedom with respect to a fixed coordinate system. The HMS utilized a transmitter mounted behind and above the helmet to create a magnetic field around the cockpit and a helmet-mounted receiver which responded to movement through the field with varying output voltages. A Honeywell HDP-5301 computer integral to the HMS System computed helmet position and rotation based on these voltages.

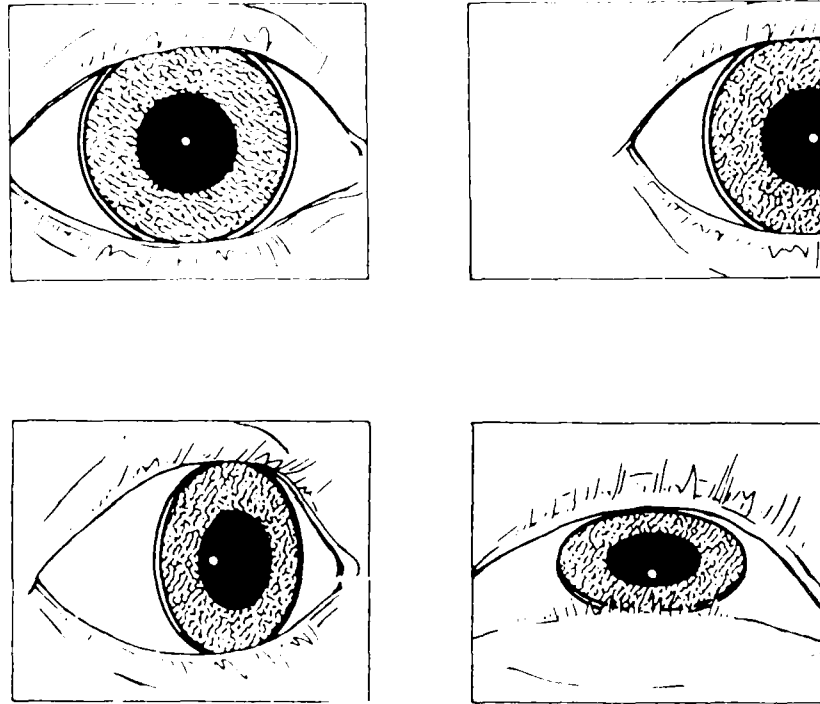


Figure 4. Illustration of the differential movement of the corneal reflection with respect to the pupil during eye movements with the head stabilized: (a) eye looking straight ahead-corneal reflection at center of pupil, (b) eye looking straight ahead but laterally displaced-corneal reflection still at center of pupil, (c) eye looking to side-corneal reflection displaced horizontally from pupil center, (d) eye looking up-corneal reflection displaced vertically from pupil center. (From Young and Sheena, 1975, p. 414).

Supporting Computer/Software System. Eye angle data and helmet rotation and position data were combined by software residing in a Data General Eclipse S/130 computer to determine eye line-of-sight with respect to a fixed coordinate system. These data were sampled and line-of-sight computed at a rate of 60 Hz. The total system error was a function of many variables, including subject characteristics (e.g., pupil size and eye lash interference) and linearization quality. RMS noise was 0.45 degrees or less at most eye positions.

The Helmet Mounted Oculometer System is connected to a PDP-11/34 mini-computer via a Network Systems Hyperchannel Adapter. The PDP-11/34 was used both to control presentation of attention cues and stimuli on the simulator monitors as well as record eye/head parameters and performance data. All data were analyzed on a Magnuson M-30/42 following the conduct of a format conversion program.

Simulator. A single-seat cockpit simulator of A-7 geometry containing two monitors and a switch panel was utilized (see Figure 5).

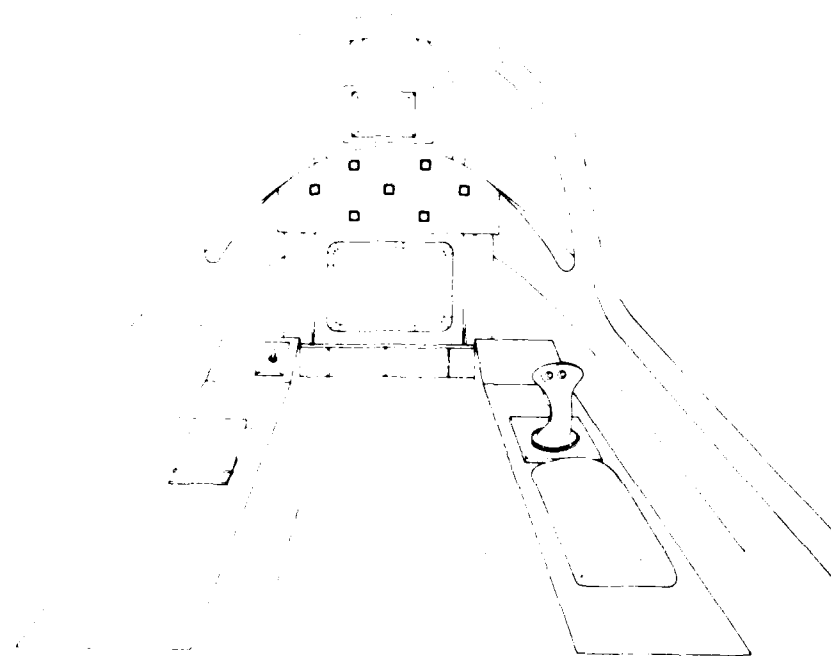


Figure 5. Schematic illustration of cockpit simulator.

The upper display was a monochrome monitor (approximately 10 by 12 cm) mounted on the cowling covering the front panel at an approximate 0.63 m viewing distance. Seven dedicated push-button switches were mounted on the upper portion of the front panel. These switches remained inoperable and unlit during the study. A color monitor (approximately 20 x 30 cm) was located below the switch panel (0.77 m viewing distance). The visual angles subtended by the heights of the upper and lower monitors were 9.1 degrees and 14.7 degrees, respectively. The centers of the two monitors were separated by approximately 23 degrees.

The cockpit simulator also contained a right console force stick fitted with 4 switches, 2 of which were thumb-actuated push-buttons. In addition, an arm rest was located behind the stick. Both an intercom and voice system (VOTRAX Type 'N' Talk) were connected to the helmet, enabling the subject to communicate with the experimenter and hear word cues. During experimental sessions, the cockpit was surrounded by a black curtain extending from the

floor to the ceiling and the room lights were dimmed. The average luminance of the symbology on the upper and lower monitors was 0.746 and 9.759 cd/m², respectively. Background luminance was near 0, resulting in a luminance contrast of approximately 100%¹.

SUBJECTS:

Subjects were 8 paid members of a contractor-maintained pool. The mean age of the 5 male and 3 female subjects was 23.25 years (SD = 3.46) and none had prior experience with this type of experiment. The subjects' corrected vision was 20/20 and their spherical refractive error did not exceed 3 diopters of hyperopia or 1.5 diopters of myopia. In addition, they had less than 0.5 diopters of astigmatic error. Two of the subjects wore soft contact lenses to correct for myopia and their data were indistinguishable from those of the other subjects. Handedness was not used as a selection criterion since the subject's tracking performance was required to reach asymptote and handedness has been found to have little effect on tracking performance (Wilson, 1972; six of the eight subjects were right handed).

Each subject was administered a standard information and consent form prior to the experiment (see Appendix A). All procedures and requirements of the Air Force pertaining to the subjects' rights, protection, and safety were satisfied.

EXPERIMENTAL DESIGN:

A mixed design with two within-subject variables and one between-subject variable was used (Figure 6). The within-subject variables were:

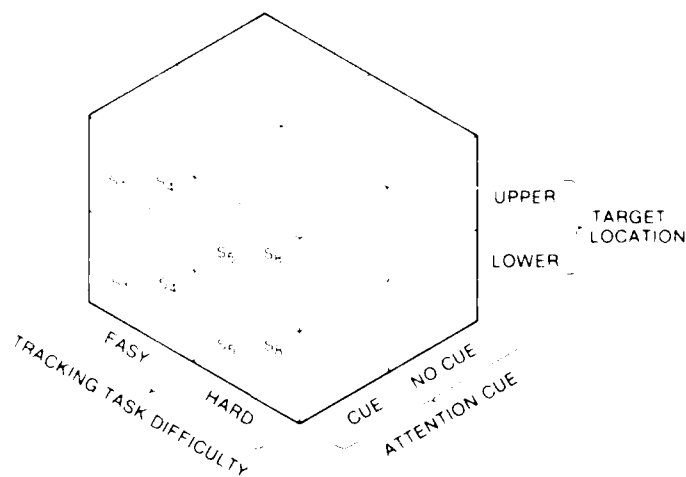


Figure 6. Experimental design.

¹ Luminance contrast = $\frac{B_1 - B_2}{B_1} \times 100$ (McCormick, 1976, p. 66)

B₁ = brighter of two contrasting areas

B₂ = darker of two contrasting areas

1) the presence versus absence of a verbal attention cue prior to the presentation of a peripheral target and 2) the location (upper versus lower) of the target on the monitor located below the switch panel (Figure 5). The between-subject variable was tracking task difficulty (easy and hard).

The first independent variable was blocked, with subjects receiving trials with the assigned tracking difficulty level across cue/no cue blocks. The order of this blocked variable was counterbalanced across the four subjects randomly assigned to each tracking difficulty level¹. The target location was randomized within each of the trial blocks. On one-half of the trials the target was in the upper location, and on the other half it was in the lower location.

SUBJECT'S TASKS:

Each subject completed two concurrent tasks: a manual tracking task presented on a centrally located monitor and a task using targets displayed on a peripherally located monitor. The subjects were instructed to minimize distractions to the tracking task, but identify targets before they disappeared (see Appendix for Subject Instructions).

Centrally Located Task. The subjects were required to complete a pursuit control tracking task on the centrally located monitor. The tracking symbology consisted of a dot as a command input and a cross hair as a system output. The subject's task was to keep the dot on top of the cross hair by exerting pressure on the force stick which controls the position of the dot on the monitor. Performance on the tracking task (root-mean-squared error) was based on the difference (in inches) between the dot and the cross hair.

Summed sine waves were used as the input forcing function. There were eight sinusoidal components which moved in both the vertical and horizontal planes so that the input appeared to the subject as a stochastic process. Past research (Junker and Levison, 1980) indicates that five sinusoids are sufficient to cause the subject to track the input as if it were a truly random process, rather than predicting the future of the input and tracking in a precognitive mode. The bandwidth of the component sine waves was systematically varied to define two tracking difficulty levels. The cutoff frequencies were low (0.1 Hz) and high (0.3 Hz) corresponding to easy and hard tracking, respectively. A pilot study was conducted to ensure that the chosen bandwidths established discernable levels of tracking difficulty. For a given difficulty level, the component sine waves were identical in amplitude. At each difficulty level, a number of forcing functions differing in the phase relationships of the components were generated and randomly assigned to runs.

¹ Unfortunately, the data for one subject assigned to the group having the cue condition first (difficult tracking level) was lost after completion of the second, no cue condition. The first condition was then readministered and the subject was required to reach asymptote again.

Peripherally Located Task. Targets were presented on the lower monitor which was vertically displaced by approximately 28 degrees from the centrally located task. Each target appeared on the upper or lower half of the monitor and was either the letter "O" or "G", surrounded by a box. These letters were chosen on the basis that they are commonly confused (Farrell and Booth, 1984) thus requiring the subject to perform saccadic eye movements in order to fixate foveally the target. The height of each target was 3.0 mm, subtending a visual angle of 0.52 degrees at the upper location and 0.54 degrees at the lower location (viewing distance 0.77 m and 0.75 m, respectively). The actual letters without the surrounding box subtended a visual angle of 0.23 degrees vertically and 0.18 degrees horizontally.

When a target was presented, the subject depressed the thumb switch on the force stick which corresponded to the target letter. The particular switch associated with the target letter was counterbalanced so that half of the subjects responded with the left and half with the right switch for the letter "O". After switch selection, the target disappeared. If the subject failed to respond to the target by the end of a 4 second interval, the letter was automatically extinguished and the error recorded.

TRIAL STRUCTURE:

Timelines showing the structure of the trials making up each run are shown in Figure 7. While the subject was completing the centrally located tracking task, trials involving the peripherally located task were initiated after the first 5 seconds of each run. A total of 20 trials were presented in each five-minute run (Figure 7a). The beginning of each trial (Figure 7b) was signalled by the verbal warning cue "READY". This warning signal was followed by a variable foreperiod of 3 to 7 seconds (mean of 5 seconds) to combat anticipatory responses. In two of the four trial blocks for each subject, the verbal cue "TARGET" was presented at the end of the foreperiod. An aural cue was used in order to avoid the onset-offset effects found with visual warnings (Ross and Ross, 1981). The interstimulus interval between the cue and the target presentation was 350 ms for all trials within the cue blocks. In the remaining two control trial blocks, no cue was presented, and the target was presented 350 ms after the end of the foreperiod. All targets were presented for 4 seconds or until the subject selected a thumb switch on the force stick. The next trial started 5 seconds after the target disappeared.

PERFORMANCE MEASURES:

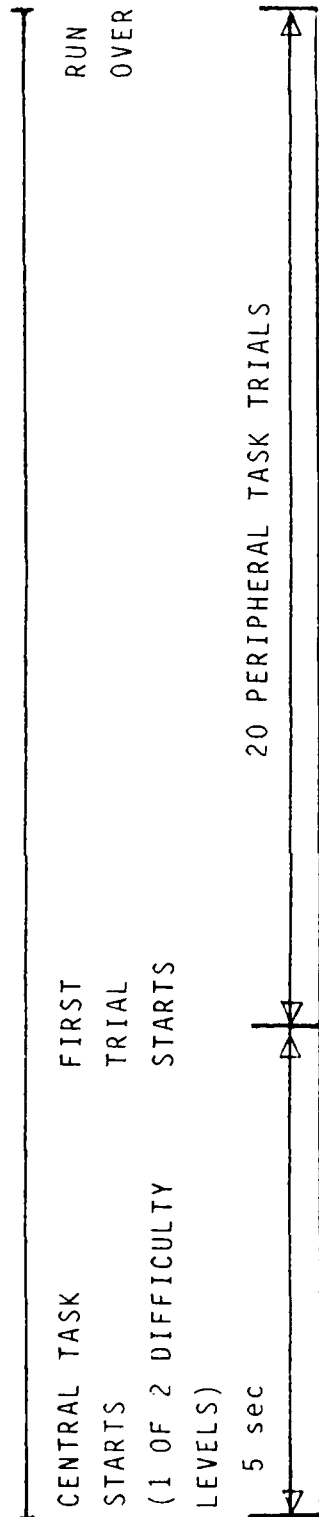
The dependent variables included eye and head response measures (reaction time and movement pattern) as well as conventional performance measures. Specifically, the following were recorded:

a) Reaction time of the eye and head: time from cue (or 350 ms before target presentation) until the eye and head began to move in the direction of the target (criterion used was the time after eye or head had moved 1.5 degrees towards the target for 3 consecutive samples or 50 ms);

b) Movement pattern of the eye and head: frequency of trials showing classical and predictive pattern;

(a) ONE OF FOUR RUNS IN A BLOCK

5 minutes



(b) ONE TRIAL

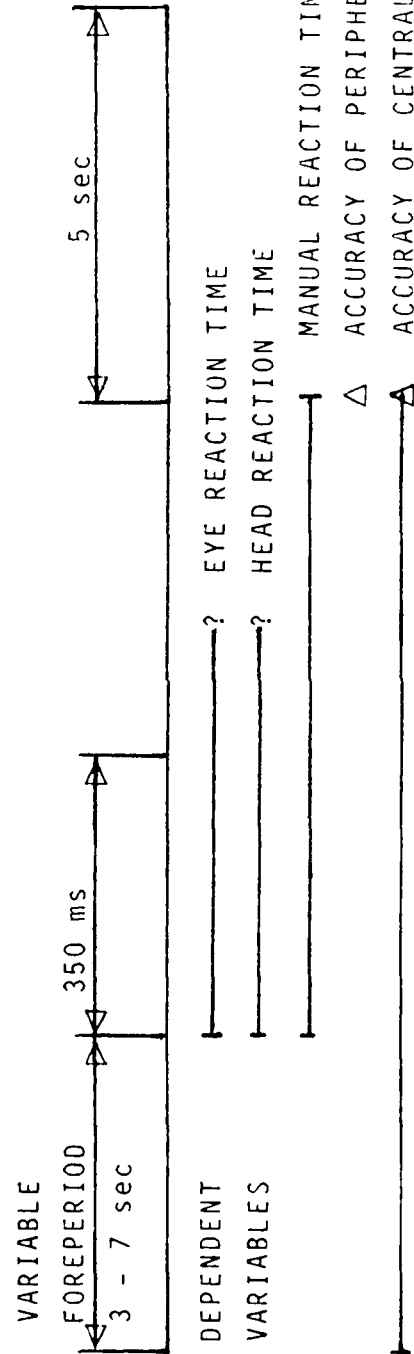
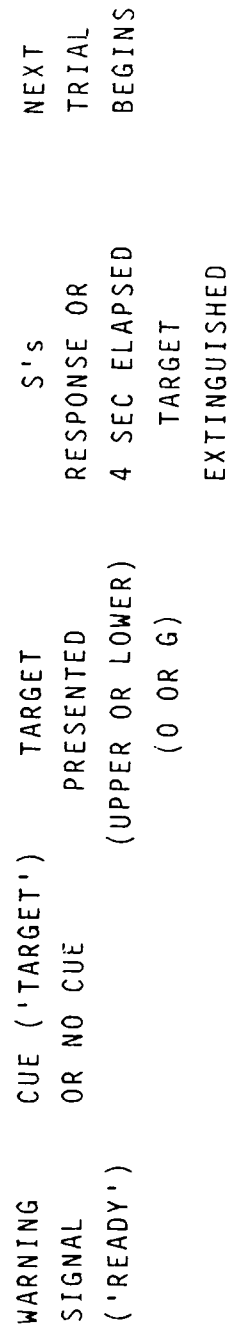


Figure 7. Time lines showing structure of the trials in each run.

c) Conventional performance measures: 1) manual reaction time: time from cue (or 350 ms before target presentation) until thumb switch on stick selected and 2) accuracy of peripherally located task (whether switch was selected and, if so, was the selection correct); and

d) Tracking performance: root-mean-squared error (RMS).

PROCEDURES:

Linearization. Prior to the experimental sessions, each subject completed a linearization procedure in order to map the unique qualities of the subject's eye to known line-of-sight angles. In this procedure, each subject fixated, while maintaining a stable helmet position and attitude, 51 LED lights which were positioned at known eye rotation angles. In this manner, the pupil video and corneal signals could be correlated with the known spatial data points. The procedure lasted approximately one hour.

Set Up. Each subject was seated in the cockpit with the seat adjusted so that the center of the upper monitor was at the subject's eye level (distance approximately 0.63 m). A modified Air Force helmet was then fitted over the subject's head and was held in place by helmet pads, a chin-strap and air bladders over the ears. The subject was also required to wear cotton gloves to help protect the reflective patch on the visor. If it was the subject's first session, a detailed explanation of the nature of the experiment, the subject's tasks and schedule was given (Appendix). Then a calibration procedure was completed before each run. To complete the calibration procedure the subject sequentially fixated four symbols displayed on the two cockpit monitors and pressed a switch. During each fixation, the computer sampled the eye position signal and stored the values for use later in translating the eye and head monitoring signals, in relation to the current helmet fit, to positions in the cockpit. At least the last five minutes of the initial set up period was conducted in the dark for eye adaptation.

Experimental Session. The subject was given instructions (Appendix) for the first block of trials followed by 16 practice runs. Additional practice runs were then conducted until the performance varied less than 7% over four 5-minute runs, as measured by mean RMS tracking error and mean manual response time to the targets. Data from the final four runs (40 trials per subject per block; Figure 6) were used in the analyses.

After 4 runs, the subject was given a short break in the cockpit. A maximum of eight runs or two trial blocks were conducted per day with the subject's infrared exposure limited to 1 hour every 48 hours. Thus, testing for each subject was limited to 3 days per week and each session, including set up, lasted approximately 1.25 hours. A total of 66 test sessions were conducted over a 10 week period of 28 testing days.

IV. RESULTS

DATA TREATMENT FOR ANALYSES:

The variables involved in the data analyses can be classified into four categories (see Table 1). The following describes the initial treatment of the data.

Table 1

Variables Addressed in the Study

1. Independent Variables (Number of Levels):
 - Difficulty of centrally located tracking task (2)
 - Attention cue condition (2)
 - Peripheral target location (2)
 - Peripheral target letter (2)
2. Eye and Head Dependent Variables:
 - Eye reaction time
 - Head reaction time
 - Percent trials showing classical and predictive eye and head movement patterns
3. Conventional Dependent Variables:
 - Manual reaction time
 - Accuracy of peripherally located task
4. Performance on Centrally Located Tracking Task

Tracking Performance. The tracking performance across subjects was examined to verify that performance (RMS error) deteriorated with increasing difficulty level. An analysis of variance (ANOVA; Kirk, 1968) showed that tracking error (RMS) increased significantly with bandwidth of the forcing function, $F(1,6) = 161.12$, $p < .0001$. (No other significant differences in RMS error were found; see Table 2.) The overall mean RMS values for the easy and hard tracking levels were 0.322 (SD = 0.072) and 0.806 (SD = 0.040), respectively.

Table 2

Summary of Analysis of Variance of Tracking RMS Error

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	0.936	0.936	161.12	0.0001*
Cue Condition (Cue)	1	0.0002	0.0002	0.09	0.7755
Diff X Cue	1	0.0006	0.0006	0.27	0.6221
Subjects Within Diff	6	0.035	0.006		
Cue X Subjects Within Diff	6	0.012	0.002		

* Significant

Accuracy of Peripheral Task. Whether or not the switch was selected in the peripheral task and, if so, whether it was correct was determined for each of the 1280 trials. Those trials with errors were then deleted from the data. Only one subject in one trial failed to respond to the target before the letter was automatically extinguished after a four second interval. Another seven errors were recorded in which five subjects selected the incorrect switch. Table 3 presents the frequency of these errors for each of the experimental variables. Error frequency did not appear to be a function of experimental condition. Considering the two types of errors together, the overall error rate was only 0.63%. This low error rate was expected due to the use of a warning signal in the trial structure and the brightness of the targets.

Table 3
Frequency of Errors for Each Experimental Condition

	Number of Trials Incorrect Switch Selected	Number of Trials Switch Not Selected
Tracking Difficulty		
Easy	2	1
Hard	5	
Cue Condition		
Cue Present	4	1
Cue Absent	3	
Target Location		
Upper	2	
Lower	5	1
Target Letter		
"O"	3	
"G"	4	1
	-----	-----
TOTAL NUMBER OF TRIALS WITH ERRORS	7	1

Performance as a Function of Target Letter. A preliminary analysis was conducted in which target letter ("G" versus "O") was treated as a within-subject variable. Since there were no significant differences in the performance measures between the two letters, the measures were averaged over these conditions for the subsequent analyses.

Initial Eye and Head Position Check. Any trial in which the eye or head was not directed at the upper monitor 350 ms prior to target presentation was deleted. This helped ensure that the eye and head reaction times reflected movement from the central monitor to the peripheral monitor.

To identify these anticipatory eye and head movements, the eye and head position 350 ms prior to each target presentation was compared to the eye and head position recorded at the center of the upper monitor during the calibration procedure before the run. If either the eye or head had moved 10 degrees or more downward from the calibration point, then the trial was deleted. A total of 108 of the 1280 trials were deleted as a result of this process. Table 4 presents the frequency of these trials for each of the experimental variables. In order to investigate whether the number of trials deleted was a function of the experimental conditions, the eye "directed down" trials and the head "directed down" trials were treated in separate ANOVAs. As can be seen in the summary of the results presented in Tables 5 and 6, there was only one significant effect. The number of trials deleted because the eye was directed down at the start of the trial with each tracking difficulty level was a function of target location, $F(1,6) = 14.49$, $p < .0089$ (Table 5). Since the eye position at the start of the trial was recorded 350 ms prior to the presentation of the target, it would seem highly unlikely that target location for the upcoming trial would have such an effect. Examination of the number of trials deleted for each subject does, however, show that two subjects had an exceptionally high number of trials deleted, (e.g. 10) in the hard tracking level, particularly with the lower targets. This variability in the data may account for the effect.

Table 4

Frequency of Trials in Which the Initial Eye or Head Position was Down

	Eye Directed Down	Head Directed Down	TOTAL
Tracking Difficulty			
Easy	14 ¹	30 ¹	44
Hard	65	0	65
Cue Condition			
Cue Present	43	1	44
Cue Absent	36 ¹	29 ¹	65
Target Location			
Upper	37 ¹	16 ¹	53
Lower	42	14	56
TOTAL - 109 Trials			

¹ For one trial, both the eye and head failed to meet the starting position criterion. This trial was treated in both the eye "directed down" and head "direction down" ANOVAs.

Table 5

Summary of Analysis of Variance of Frequency of Trial Deletions
due to Initial Eye Position

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	81.281	81.281	2.38	0.1739
Cue Condition (Cue)	1	1.531	1.531	0.07	0.7975
Target Location (Loc)	1	0.781	0.781	2.14	0.1936
Diff X Cue	1	9.031	9.031	0.42	0.5389
Diff X Loc	1	5.281	5.281	14.49	0.0089*
Cue X Loc	1	0.281	0.281	0.57	0.4772
Diff X Cue X Loc	1	0.031	0.031	0.06	0.8090
Subjects Within Diff	6	204.938	34.156		
Cue X Subjects					
Within Diff	6	127.688	21.281		
Loc X Subjects					
Within Diff	6	2.188	0.365		
Cue X Loc X Subjects					
Within Diff	6	2.938	0.490		

* Significant

Table 6

Summary of Analysis of Variance of Frequency of Trial
Deletions due to Initial Head Position

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	24.423	24.423	2.41	0.1714
Cue Condition (Cue)	1	22.561	22.561	2.21	0.1971
Target Location (Loc)	1	0.116	0.116	0.93	0.3729
Diff X Cue	1	21.000	21.000	2.06	0.2108
Diff X Loc	1	0.114	0.114	0.91	0.3771
Cue X Loc	1	0.000	0.000	.	.
Diff X Cue X Loc	1	0.000	0.000	.	.
Subjects Within Diff	6	60.750	10.125		
Cue X Subjects					
Within Diff	5 ¹	51.000	10.200		
Loc X Subjects					
Within Diff	6	0.750	0.125		
Cue X Loc X Subjects					
Within Diff	5 ¹	0.000	0.000		

¹ One subject was deleted from this analysis since half of the subject's head position data was missing due to a hardware configuration problem.

DATA ANALYSIS:

Average eye, head, and manual reaction times across trials were determined for each subject for each tracking difficulty, cue, and target location condition. The means of these dependent variables are plotted in Figures 8, 9, and 10 for each condition. Three-factor ANOVAs were performed on eye reaction time and manual reaction time with attention cue condition and target location as within-subject variables and central tracking task difficulty as a between-subject factor. An ANOVA was not conducted on the head reaction time data since 12.5% of the means were missing¹. Rather, these data were treated by a Mann-Whitney U Test (Kirk, 1968). Finally, the movement pattern of the eye and head was examined for each subject. The following will describe the results of each of these steps, in turn.

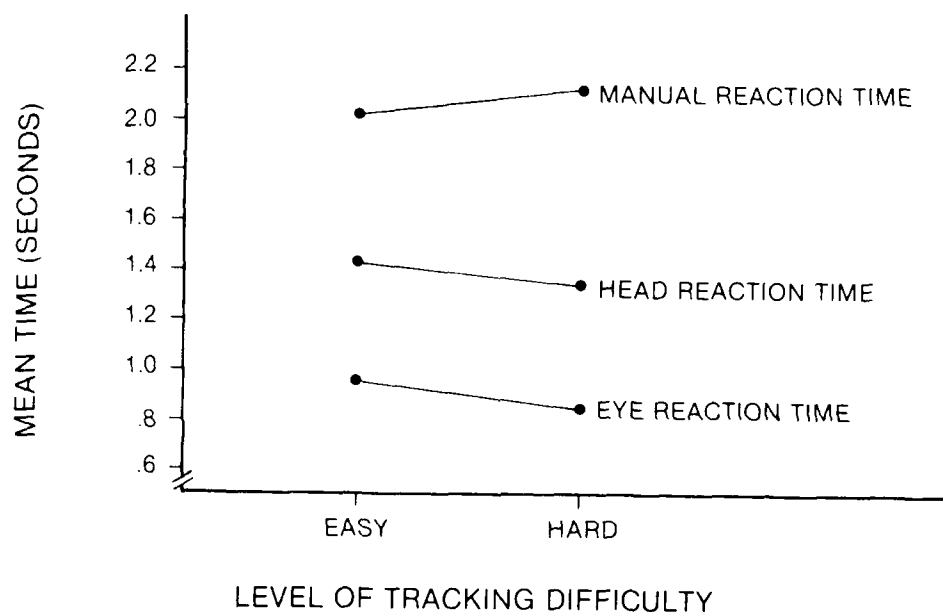


Figure 8. Mean manual, head, and eye reaction time with each level of tracking difficulty.

Eye Reaction Time. The mean reaction time of the eye across all conditions was 0.886 seconds ($SD = 0.419$). Individual subject means ranged from 0.696 to 1.071 seconds. Although the main effects in the ANOVA were not significant, there was a significant interaction of tracking difficulty level and target location, $F(1,6) = 5.96$, $p < .0504$. No other interactions were significant. These results are shown in Table 7 and the mean eye reaction time with each target location is plotted in Figure 11 as a function of tracking difficulty level. The results of a Duncan multiple

¹ Of the mean head reaction time data missing, one-third was due to a hardware configuration problem and two-thirds were from a subject whose minimal head movement failed to meet the criterion that the head move 1.5 degrees in three consecutive samples for a head reaction time to be computed.

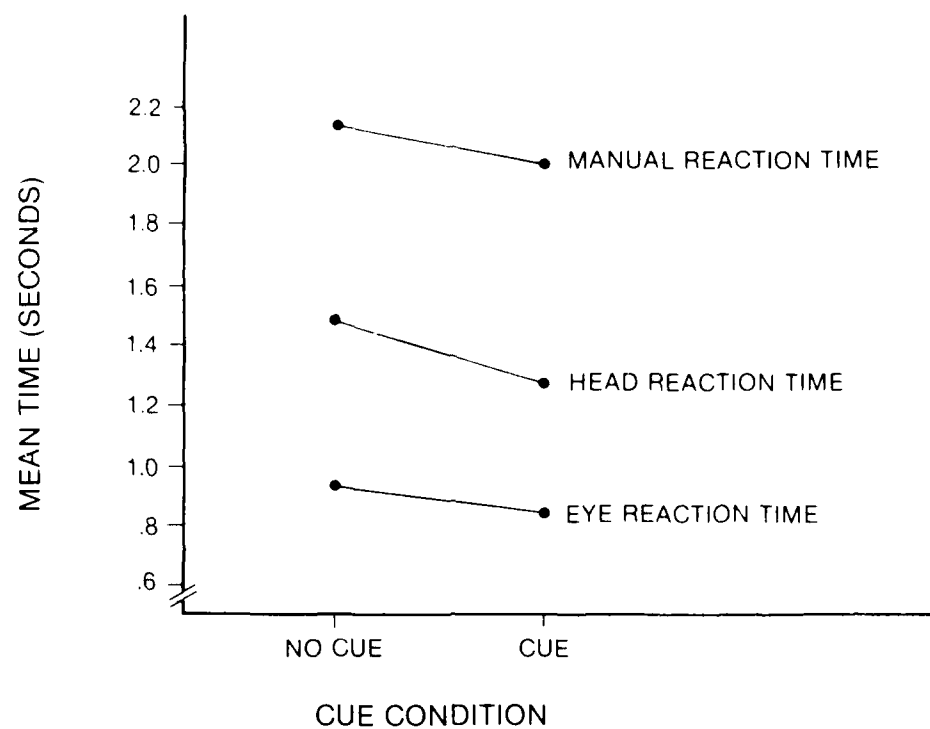


Figure 9. Mean manual, head, and eye reaction time with cue absent and cue present conditions.

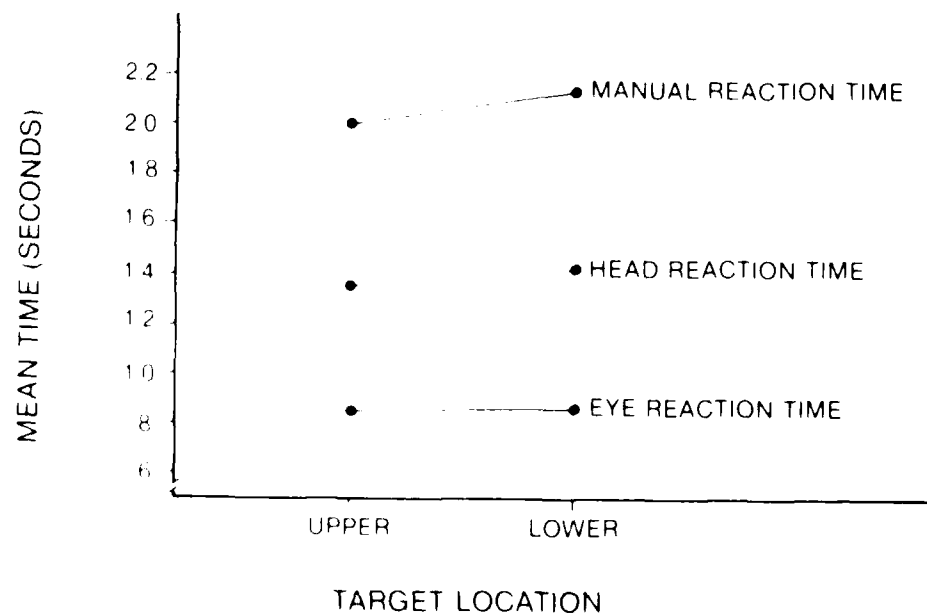


Figure 10. Mean manual, head, and eye reaction time with upper and lower target locations.

comparison procedure (Kirk, 1968) indicated that, for trials in which the target was in the upper location, mean eye reaction time was significantly faster with hard tracking (0.831 seconds, SD = 0.44) than with easy tracking (0.942 seconds, SD = 0.423; $p < .05$). In contrast, there was little difference in eye reaction time between tracking difficulty levels for targets in the lower location.

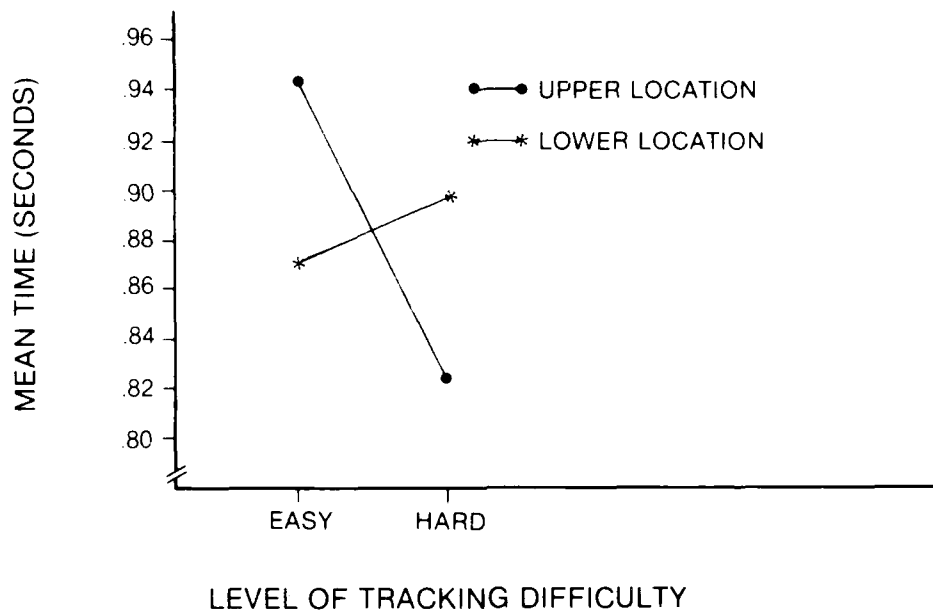


Figure 11. Mean eye reaction time for each level of tracking difficulty as a function of target location.

Head Reaction Time. The overall mean reaction time for the head was 1.328 seconds (SD = 0.313) and individual subject means ranged from 1.050 to 2.046 seconds. The results of the Mann-Whitney U Test indicated that mean head reaction time was significantly faster for the cue present condition (1.237 seconds, SD = 0.285) than for the cue absent condition (1.460 seconds, SD = 0.305; $p < .0001$; see Figure 9). There were no other significant effects.

Manual Reaction Time. The mean manual reaction time for individual subjects ranged from 1.637 to 2.743 seconds, with an overall mean of 2.095 seconds (SD = 0.394). The results of the ANOVA indicated that mean manual reaction time was significantly faster for the upper location (2.04 seconds, SD = 0.37) than for the lower location (2.14 seconds, SD = 0.41), $F(1,6) = 59.50$, $p < .0002$ (see Figure 10). This result, as well as the lack of any significant interactions, can be seen in Table 8.

Table 7

Summary of Analysis of Variance of Mean Eye Reaction Time

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	0.015	0.015	0.89	0.3807
Cue Condition (Cue)	1	0.036	0.036	2.97	0.1357
Target Location (Loc)	1	0.00003	0.00003	0.00	0.9495
Diff X Cue	1	0.005	0.005	0.40	0.5514
Diff X Loc	1	0.042	0.042	5.96	0.0504*
Cue X Loc	1	0.005	0.005	1.28	0.3008
Diff X Cue X Loc	1	0.000009	0.000009	0.00	0.9620
Subjects Within Diff	6	0.102	0.017		
Cue X Subjects					
Within Diff	6	0.073	0.012		
Loc X Subjects					
Within Diff	6	0.042	0.007		
Cue X Loc X Subjects					
Within Diff	6	0.021	0.004		

* Significant

Table 8

Summary of Analysis of Variance of Mean Manual Reaction Time

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	0.023	0.023	0.12	0.7403
Cue Condition (Cue)	1	0.068	0.068	0.82	0.401
Target Location (Loc)	1	0.073	0.073	59.50	0.0002*
Diff X Cue	1	0.100	0.100	1.21	0.3144
Diff X Loc	1	0.0004	0.0004	0.32	0.5934
Cue X Loc	1	0.004	0.004	1.54	0.2608
Diff X Cue X Loc	1	0.002	0.002	0.67	0.4434
Subjects Within Diff	6	1.158	0.193		
Cue X Subjects					
Within Diff	6	0.498	0.083		
Loc X Subjects					
Within Diff	6	0.007	0.001		
Cue X Loc X Subjects					
Within Diff	6	0.016	0.003		

* Significant

Eye and Head Movement Pattern. Out of the 1164 trials, the number of trials which did not meet the criterion (downward movement of 1.5 degrees over 3 consecutive samples) were as follows: due to head response - 630, eye response - 25, and both head and eye response - 40. For those trials in

which both the eye and head movement met the criterion, reaction times were compared to determine which movement pattern, classical or predictive, occurred more frequently. (For two trials, the eye reaction time equalled the head reaction time.) The classical pattern in which eye reaction time was less than head reaction time occurred more frequently (389 of the 467 trials) than the predictive pattern in which head reaction time was less than eye reaction time (see Table 9). The number of classical movement trials exceeded the number of predictive movement trials for each subject by at least a factor of two. One subject, however, had 100 trials (Table 9a) in which eye movement preceded head movement and 54 trials (Table 9b) in which head movement preceded eye movement. The trials showing each eye and head movement pattern are described further below.

Table 9a

Frequency of Trials Showing Classical Eye and Head Movement Pattern

SUBJECT	CLASSICAL PATTERN				TOTAL
	Cue		Location		
	Present	Absent	Upper	Lower	
Easy Tracking Level					
2	37	7	17	27	44
3	1	2	1	2	3
6	16	5	8	13	21
8	24	29	15	38	53
SUBTOTAL	78	43	41	80	121
Difficult Tracking Level					
1	54	46	54	46	100
4	15	22	12	25	37
5	33	0	17	16	33
7	50	48	48	50	98
SUBTOTAL	152	116	131	137	268
TOTAL	230	159	172	217	389

a. Classical Pattern. All eight subjects had trials in which the eye reaction time was less than the head reaction time (Table 9a). The mean number of trials for each subject showing the classical pattern was 48.5 (SD = 32.47) and the mean latency or amount of time between the eye and head response was 0.641 seconds (SD = 0.401). The results of an ANOVA indicated that none of the main effects or interactions were significant (Table 10). The difference in frequency of "classical pattern" trials between the easy and hard tracking levels did approach significance, however. The classical pattern occurred slightly more frequently with the hard tracking than with the easy tracking ($P < .0593$).

b. Predictive Pattern. Six of the eight subjects used the predictive eye and head movement pattern (see Table 9b, mean = 13 trials, SD = 18.57). The mean latency between the eye and head responses was 0.304 seconds (SD =

Table 9b

Frequency of Trials Showing Predictive Eye and Head Movement Pattern

SUBJECT	PREDICTIVE PATTERN				TOTAL
	Cue		Location		
	Present	Absent	Upper	Lower	
Easy Tracking Level					
2	0	0	0	0	0
3	0	1	0	1	1
6	2	0	0	2	2
8	5	3	5	3	8
SUBTOTAL	<u>7</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>11</u>
Difficult Tracking Level					
1	23	31	25	29	54
4	0	0	0	0	0
5	9	0	5	4	9
7	3	1	3	1	4
SUBTOTAL	<u>35</u>	<u>32</u>	<u>33</u>	<u>34</u>	<u>67</u>
TOTAL	42	36	38	40	78

Table 10

Summary of Analysis of Variance of Frequency of Trials
Showing Classical Pattern

Source of Variance	df	SS	MS	F	p
Tracking Difficulty (Diff)	1	936.037	936.037	5.39	0.0593
Cue Condition (Cue)	1	43.210	43.210	1.01	0.3608
Target Location (Loc)	1	63.688	63.688	3.08	0.1297
Diff X Cue	1	25.741	25.741	0.60	0.4728
Diff X Loc	1	26.951	26.951	1.30	0.2970
Cue X Loc	1	9.585	9.585	0.68	0.4463
Diff X Cue X Loc	1	0.670	0.670	0.05	0.8357
Subjects Within Diff	6	1041.521	173.587		
Cue X Subjects					
Within Diff	5 ¹	213.688	42.738		
Loc X Subjects					
Within Diff	6	124.021	20.670		
Cue X Loc X Subjects					
Within Diff	5 ¹	70.188	14.038		

¹ One subject was deleted from this analysis since half of the subject's head position data was missing due to a hardware configuration problem.

0.295). Since the predictive pattern only occurred in 16.8% of the trials and the majority of these were due to one subject, these data were not treated in a statistical analysis.

SUMMARY OF RESULTS:

The results are summarized in Table 11. Clearly, each dependent variable was sensitive to different aspects of the experimental paradigm. Eye reaction time was sensitive to tracking task difficulty, but only when the target was in the upper location ($p < .05$). When tracking was easy, the eye reaction time was shorter for the more distant target. When tracking was difficult, this relationship was dramatically reversed. Head reaction time was the only measure sensitive to the presence of a cue ($p < .0001$). Manual reaction time, the conventional measure of response, was sensitive only to the distance of the target ($p < .0002$). Mean manual reaction time was faster for the upper target location compared to the mean reaction time recorded for the lower location.

Table 11

Summary of the Effects of Each Variable on Reaction Time Measures

Measures	<u>Experimental Variable</u>			
	<u>Tracking Difficulty</u>	<u>Cue/No Cue</u>	<u>Target Location</u>	<u>Interactions</u>
Eye	No Effect	No Effect	No Effect	Tracking*Location
Head	No Effect	Faster With Cue	No Effect	No Effect
Manual	No Effect	No Effect	Upper Faster	No Effect

V. DISCUSSION

The purpose of the present experiment was to examine the eye and head response to a cue to refixate at targets which were vertically displaced from the normal line-of-sight. Specifically, a dual task paradigm was employed to characterize the eye and head response for the following: a) two difficulty levels of the centrally located tracking task; b) two target locations which were vertically displaced from the centrally located task; and c) presence or absence of an attention cue prior to target presentation. The following will describe the effect of these three factors on reaction time and movement pattern of the eye and head, in addition to manual reaction time. First though, the overall characteristics of the eye and head response will be addressed.

EYE AND HEAD RESPONSE:

In the current experiment the overall eye reaction time was 386 ms (SD = 0.419). This is greater than that reported by Robinson (1979; up to 700 ms) for a similar dual task paradigm. There are many factors that can account for these differences in reaction time. For example, system delay in calculating a change in the eye and head position signal (approximately 200 ms in the present experiment) can increase reaction time measures (Calhoun, Arbak, and Boff, 1984). A second factor is the criterion used in determining when the eye and head started to move towards the target. In the present experiment, the conservative criterion (downward eye or head movement of 1.5 degrees over 3 consecutive samples) may have increased reaction time. Since the system delay and movement criterion were not reported in earlier studies (e.g., Robinson, 1979), it is not possible to determine whether these two factors account for the differences between the present and previous studies.

A third factor that was different between these studies and which may have affected reaction time was target location. The present experiment used targets which were vertically displaced from the centrally located task as opposed to earlier studies which examined targets in the horizontal periphery. This factor seems plausible in that the eye and head movement patterns in the present experiment were different in many ways from those reported in the past. First, in the present experiment, the subjects more frequently used a classical movement pattern in which there was a large delay of the head movement after the eye movement was initiated (83.20% of the trials). This is an opposite trend from the results of an automobile mirror sampling study in which the subjects had a horizontally peripheral monitoring task in addition to a centrally located monitoring task (Mourant and Grimson, 1977). In the automobile study, 63% of the trials showed a predictive movement in which the head response preceded the eye response. A second difference was the latency or delay between the eye and head response. In the present experiment, the average time between the eye and head response was about twice as long for the classical pattern than the predictive pattern. In previously reported data, however, the difference was in the opposite direction. The latency between the eye and head response in predictive pattern data was double (Mourant and Grimson, 1975) or quadruple (Robinson and Bond, 1975) that of the classical pattern. Moreover, the overall latencies for both eye and head movement patterns in the present experiment were much longer than those reported with targets in the horizontal plane. The average latencies in the present experiment were 641 ms (classical) and 304 ms (predictive) whereas typical latencies in previously reported classical and predictive patterns were 50 ms and 100-200 ms, respectively (Nelson, et al., 1978). A third difference between the present experiment and earlier studies was the degree of correlation between the eye and head reaction times in each movement pattern. The correlation coefficients were 0.48 (predictive) and 0.21 (classical) for the present data whereas Robinson and Bond (1975) reported 0.76 (predictive) and 0.98 (classical). These results illustrate that many characteristics of the eye and head movement pattern were different with vertically displaced targets compared to earlier data with horizontally displaced targets.

In order to characterize these movement patterns conclusively, additional experimentation is needed to examine eye and head response in both the vertical

and horizontal planes. In this research, the current helmet configuration should be used for both vertical and horizontal refixations in case the additional mass (0.198 kg) on the modified helmet affects the subjects' ability to reposition the head quickly and accurately. Although none of the subjects in the present experiment commented that the eye and head monitoring system was obtrusive, a few stated that it seemed easier to reacquire the centrally located tracking task when they minimized head movement in the target identification task. Thus, the frequent use of the classical movement pattern may reflect a tendency for the subjects to keep their head directed slightly below the upper monitor in order to minimize the amount of head movement required in the peripheral task. In fact, the head position 350 ms before the target was presented averaged 1.44 degrees lower than the eye position at the same time.

It is also important, in future experimentation, to use the same centrally located task during refixations in the vertical and horizontal planes. The nature of the ongoing task must be controlled since it may account for some of the differences found between the present and past research. This is illustrated in the present experiment by the effect of the dual task paradigm on eye and head movement patterns. This finding, in addition to the effect of cue condition, will be addressed next.

FACTORS AFFECTING EYE, HEAD, AND MANUAL REACTION TIME:

The present experiment is the first known evaluation in which the effect of central task difficulty level, target location, and presence of a cue were examined in a dual task paradigm for both eye and head measures in addition to the conventional manual reaction time. Each of these factors will be discussed below.

Dual Task Paradigm. The subjects' two tasks were to complete a centrally located pursuit tracking task and to identify targets which were vertically displaced from the normal line-of-sight. Performance was evaluated for two levels of each task: easy and hard tracking and upper and lower target location. The results showed that eye reaction time was significantly faster in the hard level compared to the easy level when the targets were in the upper location (Figure 11). In addition, mean manual reaction time was longer for the lower target location than for the upper location. These results were expected due to several factors. First, targets in the lower location were not visible for most subjects without some eye and head movement. However, when the bright and relatively large targets were in the upper location, the subjects could tell, with minimal eye and head movement, when a target was presented. Also, the heightened arousal level in the hard tracking condition may have improved, according to Easterbrook's theory (1959), the subject's ability to select the relevant cue of changing luminance in the periphery. A second factor contributing to these results was the longer visual distance the subjects traveled to acquire the lower targets. The distance probably created a greater disruption with the hard tracking task. It would also explain the subjects' more frequent use of a movement pattern in which the eye response precedes the head response. In other words, when the subjects did not see the

peripheral luminance cue that an upper target was presented, they usually started the more rapid eye towards the lower target, rather than the slower moving head.

Repetition of the present experimental paradigm with smaller, less bright targets in several locations on the lower monitor would help clarify this finding. Use of more target locations in a follow-on experiment would also address whether there are functional visual fields in acquiring targets in the vertical periphery similar to those identified for the horizontal periphery by Sanders (1970). Although examination of the angles at which the eye and head began to move as a function of target location was outside the scope of the present experiment, the results showing changes in the eye and head response as a function of target location certainly indicate that this is an hypothesis worth further investigation.

Follow-on research should also examine additional tracking difficulty levels in a within-subjects design. Not only would this allow further investigation of arousal effects on cue selectivity, but it would indicate whether eye and head movement patterns are related to the subject's allocation of attention between tasks. Previous research has shown a narrowing of attention such that performance on a peripheral task deteriorated when the incentive for good performance on the centrally located task increased (Bahrick, et al., 1952). This result, together with Nelson's et al. (1978) finding that subjects' use of a predictive movement increases with central task complexity suggests that when the centrally located task is demanding, subjects use the predictive movement pattern which allows the eye to maintain foveal fixation on the central task longer. This hypothesis would explain the lack of predictive eye and head movements in the present experiment. Even though the instructions were to "minimize distractions to the tracking task, but identify targets before they disappeared", it would seem from the extremely low error rate in the peripheral task that the subjects treated the letter identification task as primary and the tracking task as secondary. In order to test this hypothesis, eye and head movement patterns should be observed with several tracking difficulty levels in conjunction with an explicit payoff matrix which controls the allocation of attention between the central and peripheral tasks. Since it has been suggested that subjects' eye and head movement patterns change with experience (Mourant and Grimson, 1977), it may also be desirable to systematically examine the patterns over time.

Cue Condition. Since mean head reaction time was significantly faster when a verbal cue was presented 350 ms prior to target presentation, it appears that it was sensitive to the general preparatory or alerting process. Mean eye and manual reaction times were also faster in the cue present condition, although these differences were not statistically significant. These results suggest that these measures may be useful in the evaluation of candidate cues in directing an operator's attention to a particular display or control. To pursue this hypothesis further, eye and head reaction time should be compared to manual reaction time with different attention cue modalities and several interstimulus intervals between the cue and target presentation.

VI. CONCLUSIONS

The present experiment is the first known evaluation in which both eye and head measures in addition to the conventional manual reaction time were examined in a dual task paradigm with an attention cue. The subjects' tasks were to: complete a pursuit control tracking task presented on an upper monitor by making inputs to a force stick, and identify targets which were vertically displaced from the normal line-of-sight. The specific conclusions of this experiment are:

1) Since the eye and head response was different in the present experiment from that observed in earlier studies, further experimentation is needed to conclusively determine the effect of: a) target location (vertically versus horizontally displaced) and b) the subject's attention allocation between tasks.

2) Eye (with hard tracking) and manual reaction time increased the farther a target was vertically displaced from the centrally located, ongoing task.

3) The presence of a verbal cue prior to target presentation decreased head reaction time.

4) As shown above, eye, head, and manual reaction time did not respond similarly to the factors manipulated in this experiment. This demonstrates the importance of examining further all three measures in response to an attention cue in a dual task paradigm.

The differences in eye and head response as a function of the factors examined in this experiment indicate that these relatively nonobtrusive measures should be evaluated further for use in the design of attention cueing systems. In the case of cockpit design, use of eye/head movement parameters may enable detection of a pilot's awareness of rapid changes in information presented without requiring the pilot to make a separate response. However, if manual reaction time and eye and head response are differentially sensitive to the effectiveness of attention cues, then experimenters must carefully choose the proper index of an operator's response to a cue.

APPENDIX

Eye and Head Response to an Attention Cue

Subject Instructions

INTRODUCTION

Thank you for agreeing to serve as a subject in the Helmet Mounted Oculometer Facility. As we explained to you during the linearization process, the unique feature of this system is its ability to accurately measure your helmet and eye position. The purpose of this next experiment is to examine how your eye and head respond during combined tracking and letter identification tasks, with and without the presence of a cue. Through your efforts, we will be able to determine whether measures of eye and head movements are useful to the design of attention cues for future cockpits.

HELMET FIT

Now we'd like to get you set up in the cockpit. As you climb in watch out for the switch on the left console. Next we'll adjust your seat height before fitting the helmet on you. There are several things you need to know about the care of the helmet and visor:

1. First of all, the visor must be kept very clean. Thus, you are required to wear cotton gloves throughout the entire session. You should still avoid touching the visor, but in the event you do, it serves as an aid in reducing the amount of oil that gets on the visor. (Please inform us if you experience any irritation from the gloves.)
2. Once we place the helmet on your head with the necessary helmet pads inserted, fasten the chin-strap. (The chin-strap may need some adjustment to fit snugly under your chin.)
3. Once the chin-strap is in place inflate the ear bladders until the helmet feels snug on your head. Remember, fasten the chin-strap before inflating the ear bladders.
4. We will raise and lower the helmet visor for you, and attach the cables to the upper right side of your seat.
5. In the event you need to move or reposition the helmet please advise us so we may assist you.
6. Remember, be very careful not to bump the visor against any surface, or touch the visor, especially the reflective patch over your right eye.
7. If an emergency should occur and you need to get out of the helmet without assistance, perform the following steps in order:

- a. Raise the visor by pulling the visor clip on the upper left side of the helmet outward.
- b. Let the air out of the ear bladders by turning the valve near the bulb.
- c. Unfasten the chin strap.
- d. Release the cables on the upper right of the seat by pulling the velcro strap.
- e. Carefully take off the helmet and place it on the seat without bumping the visor.
- f. Exit through one of two doors in the lab.

TASKS

1. You will have two tasks in this experiment. One of your tasks will be to complete a manual pursuit tracking task on the upper monitor while the other task will be to identify letters that are frequently presented on the lower monitor. You are to minimize distractions to the tracking task, yet identify the letter before it disappears. Your performance on both tasks will be recorded and analyzed.

2. The symbology presented on the upper monitor for the tracking task will be a dot and a cross-hair. By applying force on the joystick, your task is to put the dot on top of the continually moving cross-hair. Your performance will be measured in terms of the average distance of the dot from the cross-hair during a run. The particular tracking difficulty level that you have been randomly assigned to is just one level of several being examined in this study so we expect your performance on the tracking task to differ from other subjects'.

3. As you are tracking, the speech synthesizer will frequently say "READY" to warn you that a trial is to begin for your letter identification task.

NO CUE - Shortly after the "READY" signal,

CUE - You will hear the cue "TARGET" to inform you that a letter is to be presented in less than half a second.

Then, either the letter "O" or "G" will appear in a square somewhere on the lower monitor. Your task is to push the (left/right) switch on the joystick if it is the letter "G" and the other switch if it is the letter "O". Both the speed and accuracy of your switch selection will be recorded. The

letter will disappear when you depress a switch. If, for some reason, you do not push a switch, the letter will disappear about 4 seconds after the warning cue. This type of error will also be recorded.

4. Follow these procedures throughout the entire run. Try to minimize disruption to the tracking task--yet you must identify each letter before the 4 second exposure terminates. Following the last letter identification trial for each run, there will be a short period in which your only task will be tracking. Continue performing the tracking task until the cross-hair disappears from the monitor.

Do you have any questions at this point?

BORESIGHT

1. Before each run, it is necessary to "tune" the system to the particular characteristics of your eye and the position of the helmet on your head. This procedure, which we call "boresighting," includes staring at symbols on the upper and lower monitors and pressing a switch to collect data.

2. To begin the boresight procedure, depress the center red switch on the front switch panel. The verbal command "START BORESIGHT" will be issued by the speech synthesizer. Then look at the dot in the center of the upper monitor. When you feel that you have a good, steady fixation on the dot, depress the trigger switch located on the back of the joystick. This will result in the presentation of a symbol in the center of the lower monitor. Again, look at it and when you feel that you have a good steady fixation, depress the trigger switch to bring up the next symbol. There will be a total of three symbols presented on the lower monitor, center first, followed by upper and lower locations. Once you depress the trigger switch for the lower symbol, the speech synthesizer will respond with "END BORESIGHT" and data collection will begin on your two tasks.

3. Between the runs, the speech synthesizer will issue the command "REBORESIGHT" and you are required to repeat the procedure I just described for the dot on the upper monitor and the symbols on the lower monitor.

Unless you have any questions, I'll bring up the system now.

STARTUP

1. First, I will close the curtain and dim the overhead lights. Your eyes will be dark-adapted for about 5 minutes. You may use this time to rest your eyes, but we ask that you don't push any switches.

2. We will be in communication through the intercom during the entire session. Feel free to ask questions during the next few training runs.

3. After the dark adaptation period, I'll inform you that I'm turning on the light source (you'll see the red filament image reflect off the

visor). While it warms up, I'll start the experimental control program. When the computer starts beeping it's ready to collect data. I may have to adjust your helmet some to get a better image of your eye. I will also tell you when to begin the boresight procedure by depressing the center red switch. Please let me know between runs if you need to have your helmet adjusted, or if you have any questions.

We will run four 5-minute runs, give you a short break in the cockpit, and then another four 5-minute runs. It may take several weeks, running approximately every other day, to complete the training sessions and collect the data that we need.

4. Any Questions?

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